III. Wastes and Other Byproducts of the Cold War

A 55-gallon drum ready for storage in the basement level of the K-25 Gaseous Diffusion Plant. K-25 has prepared 45 basement vaults for the storage of low-level and mixed hazardous wastes. These vaults will be able to hold some 63,000 drums. A coat of epoxy sealant covers the renovated vault floor, adding one more level of containment for wastes stored here. *K-25 Gaseous Diffusion Plant, Oak Ridge, Tennessee. January 10, 1994.*

Every step in the production of materials and parts for nuclear warheads generated waste and other byproducts. Every gram of plutonium, each reactor fuel element, every container of enriched uranium, and each canister of depleted uranium has radioactive waste associated with it. The graphite bricks used by Enrico Fermi for his primitive reactor at the University of Chicago were buried as radioactive waste at the Palos Forest Preserve in Cooke County, Illinois. The acid used to extract the plutonium for the first nuclear test explosion in the Alamogordo desert of New Mexico is now high-level waste stored at the Hanford Site in the State of Washington.

The wastes are classified into several categories, depending on the hazards they pose, the length of time they remain radioactive, or their source. They require safe storage and disposal, and they often need special treatment before either storage or disposal.

The nuclear weapons industry typically used waste-disposal methods that were considered acceptable at the time–especially between 1943 and 1970. By today's standards, however, these methods would be considered primitive. One result of these practices is significant contamination of soil and ground water (see Chapter IV). For example, some types of liquid waste were held in ponds for evaporation because engineers did not expect radioactive material to seep into the soil and ground water as rapidly as it did.

Every step in the production of materials and parts for nuclear warheads generated waste and other byproducts.

Nuclear weapons wastes are as varied as the processes that produced them: intensely radioactive acids from reprocessing; slightly radioactive shoe covers from walking across factory floors; chemical solvents from performing purity tests. Each of these wastes differs in physical characteristics, chemical form (salt-cake, acidic liquid), and radioactivity (short-lived tritium, long-lived plutonium). Each requires different handling and the volume of waste continues to grow. Every time workers suit up and walk into a contaminated building for an inspection, they create more waste (gloves, shoe covers, disposable coveralls). Each time a ventilation system is cleaned out, waste is the result. Sampling excavated radioactive solids creates waste. The process of stabilizing and cleaning up old facilities generates huge volumes of additional waste.

The radioactivity level of all this waste is slowly decreasing. With the shutdown of the last production reactor in 1988, the total amount of radioactivity in the system stopped growing and is now decreasing at the decay rate of the various isotopes. Some isotopes decay quickly, with half-lives of only a few minutes, others have half-lives of many thousands of years.

This chapter follows the path of major process materials through the complex. It starts with a discussion of spent fuel, then considers highly radioactive waste from chemical separation. Next comes a discussion of plutonium, then of transuranic waste. The chapter continues with sections on low-level waste, hazardous waste, mixed radioactive – and – hazardous waste, and finally materials left in the inventory that were once used in production but no longer have a clearly identified use. Uranium-mill tailings are considered to be contamination rather than waste and are discussed in the chapter on contamination.

Categories of Radioactive Wastes and Byproducts

The Department is responsible for managing large inventories of nuclear waste and byproducts in accordance with national and international principles. These principles require protection of the environment and health for present and future generations, compliance with independent regulatory agencies, and a practicable minimum of waste generation. The primary waste and byproduct categories are defined as follows:

Spent fuel: fuel elements and irradiated targets (designated “reactor-irradiated nuclear material” and often called simply “spent fuel”) from reactors. The Department’s spent fuel is not categorized as waste, but it is highly radioactive and must be stored in special facilities that shield and cool the material.

High-level waste: material generated by the reprocessing of spent fuel and irradiated targets. Most of the Department’s high-level waste came from the production of plutonium. A smaller fraction is related to the recovery of enriched uranium from naval reactor fuel. This waste typically contains highly radioactive, short-lived fission products as well as long-lived isotopes, hazardous chemicals, and toxic heavy metals. It must be isolated from the environment for thousands of years. Liquid high-level waste is typically stored in large tanks, while waste in powdered form is stored in bins.

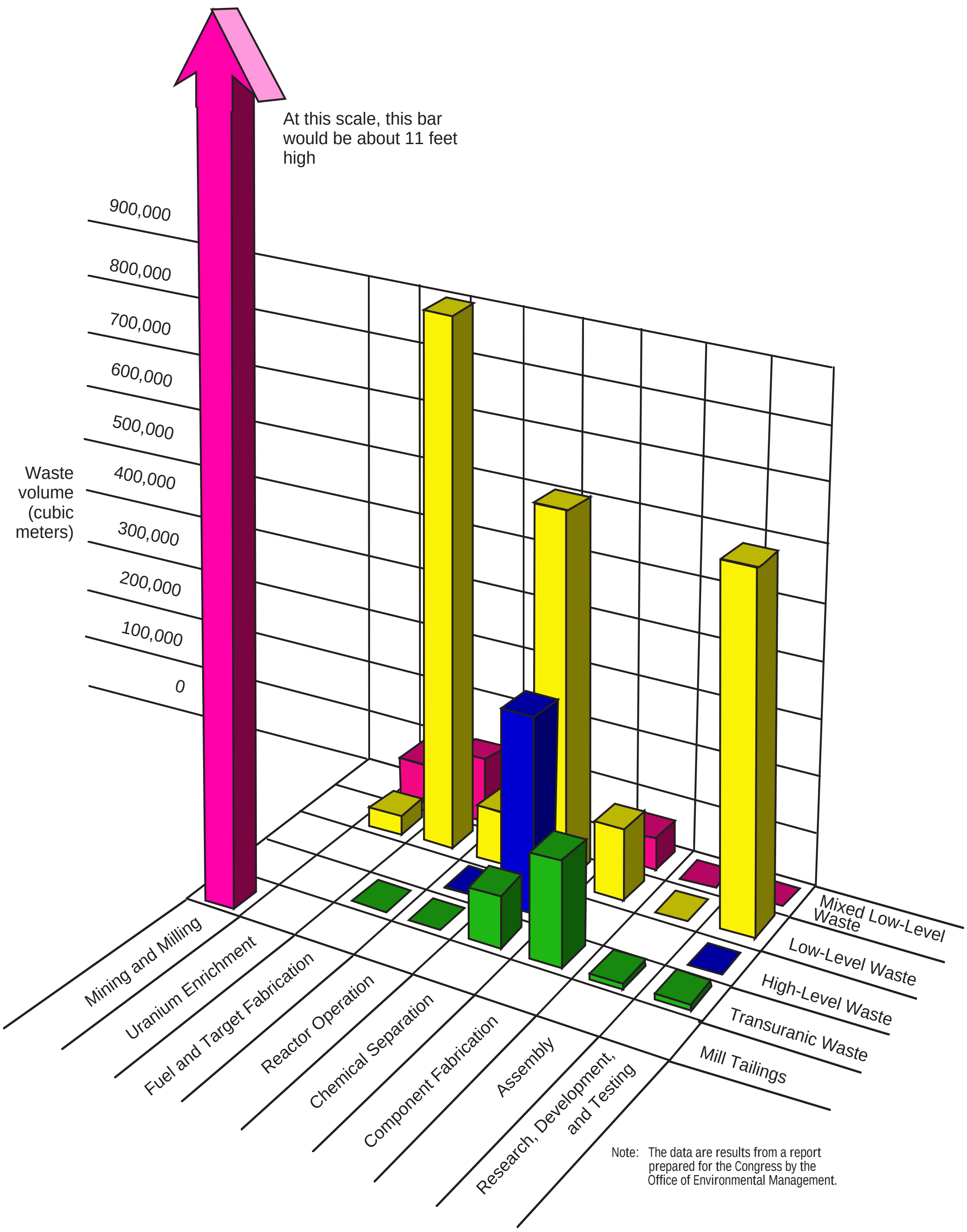
Transuranic waste: waste generated during nuclear weapons production, fuel reprocessing, and other activities involving long-lived transuranic elements. It contains plutonium, americium and other elements with atomic numbers higher than that of uranium. Some of these isotopes have half-lives of tens of thousands of years, thus requiring very long-term isolation. Since 1970 transuranic waste has been stored temporarily in drums at sites throughout the complex.

Low-level waste: any radioactive waste that does not fall into one of the other categories. It is produced by every process involving radioactive materials. Low-level waste spans a wide range of characteristics, but most of it contains small amounts of radioactivity in large volumes of material. Some wastes in this category (e.g., irradiated metal parts from reactors) can have more radioactivity per unit volume than the average high-level waste from nuclear weapons production. Most low-level waste has been buried near the earth’s surface. A limited inventory remains stored in boxes and drums.

Mixed waste: waste that contains both radioactive and chemically hazardous materials. All high-level and transuranic waste are managed as a mixed waste. Some low-level waste is mixed-waste.

Uranium-mill tailings: large volumes of material left from uranium mining and milling. While this material is not categorized as waste, tailings are of concern both because they emit radon and because they are usually contaminated with toxic heavy metals, including lead, vanadium, and molybdenum.

Volumes of Wastes and Other Byproducts Generated by Nuclear Weapons Production Activities During the Cold War



Note: The data are results from a report prepared for the Congress by the Office of Environmental Management.

Each step in the process of designing, producing, testing, and maintaining nuclear weapons produces wastes and other byproducts. Facilities across the United States have contributed to this process and generated a variety of wastes as a result. Knowing how much waste of what type has been generated by what steps in the process is critical for planning how to manage the wastes and possibly redesigning, for the future, the steps in the process to minimize the generation of these wastes and the attendant problems. This graph illustrates the volume of five types of waste and byproducts generated by nuclear weapons activities during the Cold War, with mill tailings accounting for about 96 percent of the total volume. Another method for measuring the waste is according to the amount of radioactivity contained in the various waste types (see page 32).

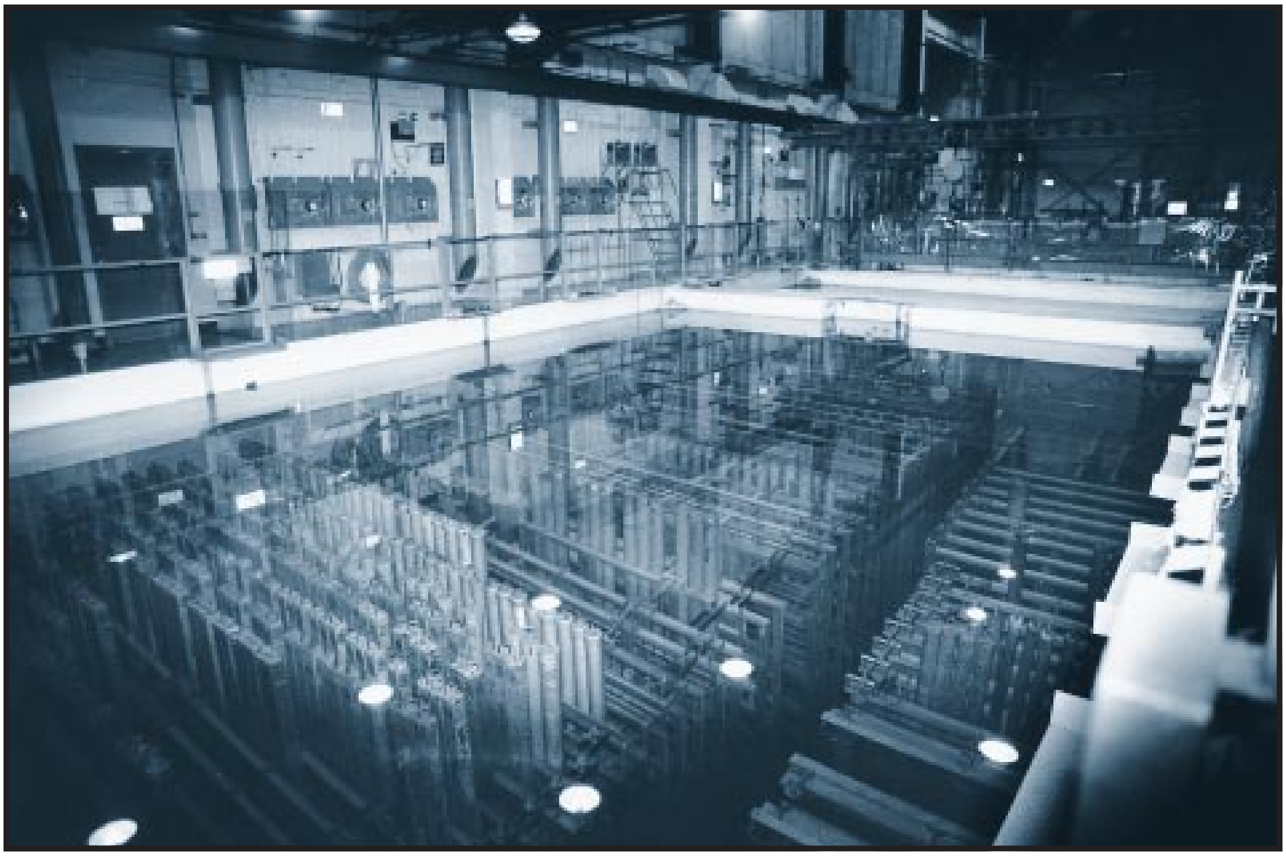
A cask for shipping spent fuel stands empty after its cargo of irradiated nuclear fuel has been deposited into the nearby spent-fuel pool for storage. A worker is completing decontamination of the cask so that it can be reused. The spent-fuel pool in the background holds 22 million gallons of water. *Idaho Chemical Processing Plant, Fuel Storage and Treatment Facility, Building 666, Idaho National Engineering Laboratory. March 17, 1994.*

Spent Nuclear Fuel

To produce plutonium and tritium for nuclear warheads, the United States operated 14 nuclear reactors. The first one started in 1944; the last one was shut down in 1988. During that time, most of the nuclear fuel rods and targets irradiated in the reactors were reprocessed to extract the plutonium as well as the leftover enriched uranium for reuse. The process produced liquid high-level waste, transuranic waste, low-level waste, and mixed waste.

During the Cold War, the Government stored its spent-fuel elements before reprocessing – and only as long as necessary for them to “cool off” by radioactive decay. Declining demand for plutonium and highly enriched uranium, however, steadily reduced the pace of reprocessing. When the Department announced the phaseout and eventual complete cessation of reprocessing in April 1992, it had accumulated approximately 2,700 metric tons of spent fuel in nearly 30 storage pools. About 99 percent of this spent fuel is stored at four sites: the Hanford Site in Washington, the Savannah River Site in South Carolina, the Idaho National Engineering Laboratory, and West Valley in New York. Most spent fuel is stored indoors, in pools under water that is cooled and filtered; some spent fuel is kept in dry storage.

The amount of spent fuel stored by the Energy Department is much smaller than the amounts stored by the commercial nuclear power industry, but Department of Energy fuel often presents greater safety problems. The commercial industry currently stores approximately 30,000 metric tons at more that 100 nuclear reactor sites around the United States; this is about 10 times the mass stored by the Energy Department. Unlike fuel for commercial nuclear reactors, however, most of the Department’s spent fuel was designed to be reprocessed. Its cladding – the outer layer of zirconium metal – was not designed for long-term storage. As a result, some of the stored spent fuel has corroded, leading to a number of potential safety problems. Also, some of the Department’s

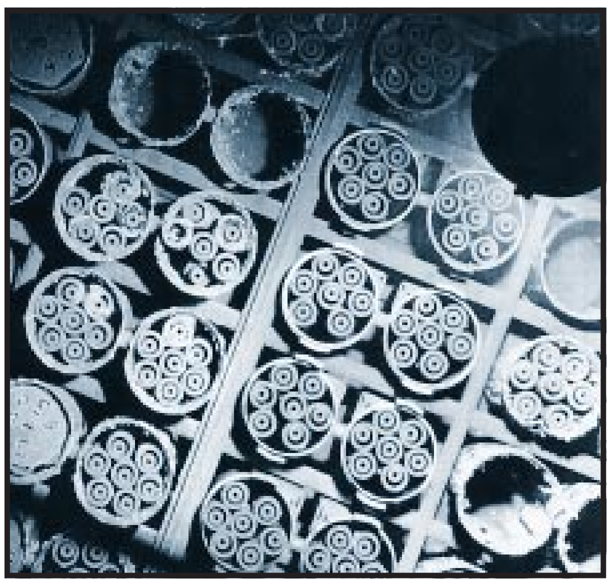


Pool for the storage of spent fuel. This pool is 28 feet deep; 7 feet of water cover the top of the highly radioactive spent-fuel elements. Water cools the fuel and also acts as radiation shielding. *Receiving Basin for Offsite Fuel, Savannah River Site, South Carolina. January 7, 1994.*

spent fuel contains highly enriched uranium and thereby presents much greater security and safety concerns than commercial spent fuel.

The Department's challenge is to safely store this spent fuel for the years that will pass before a geologic repository is available for permanent disposal. Unfortunately, many existing storage facilities do not meet current commercial or government safety standards; some of them are nearly 50 years old. Some pools are unlined and do not have adequate provisions for the control of water chemistry, a situation that is likely to lead to corrosion and leakage. A lesser concern has been the potential for an inadvertent nuclear chain reaction (a so-called "criticality event") resulting from accidents in handling or storage.

Ninety-nine percent of government owned spent fuel is stored in four states: Washington, South Carolina, Idaho, and New York.



Corroding spent-fuel elements from the Hanford N Reactor are stored in an unlined concrete pool in the 105 K-East area. Corrosion releases radioactive materials to pool water, posing a hazard to workers. *Hanford Site, Washington.*

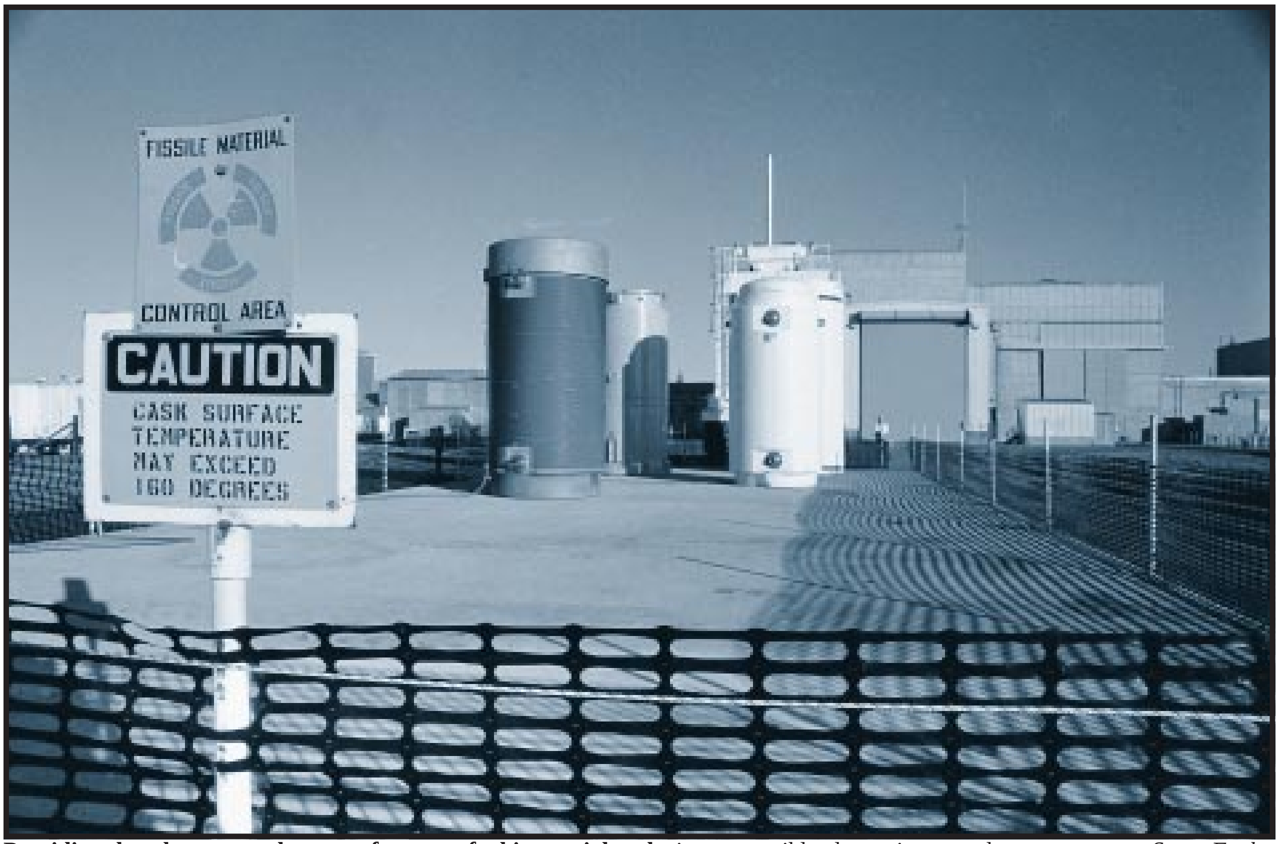
Straddle carrier for moving casks of spent fuel into dry storage. The Department of Energy is replacing underwater pool storage with these dry casks to increase safety and reduce costs. *Idaho National Engineering Laboratory. March 17, 1994.*

Reducing Risks from Spent-Fuel Storage

The Department of Energy has evaluated its facilities for spent-fuel storage and it is developing new storage methods and facilities. Material posing the highest risk is being moved out of inadequate facilities, repackaged and stabilized, and placed in more secure locations. For example, a spent-fuel storage pool at the Idaho National Engineering Laboratory is earthquake resistant, can retard corrosion by maintaining proper water chemistry, and has a leak-detection system. Spent fuel from other areas at the Laboratory is being consolidated there.

Spent nuclear fuel that poses the highest risks is being moved out of inadequate facilities, repackaged, stabilized, and placed in more secure locations.

At the Hanford Site, radioactive sludge and spent fuel exist in an obsolete facility a few hundred yards from the Columbia River. In the past, one basin leaked millions of gallons of contaminated water into the ground. The spent fuel and sludge will be packed in new containers and moved away from the river to a modern storage facility. An environmental study is considering long-term dry storage of Hanford spent fuel. In the meantime, Hanford's fuel pools are being upgraded to minimize the potential for leaks and render them less susceptible to earthquake damage.



Providing dry aboveground storage for spent fuel in special casks is one possible alternative to underwater storage. *Spent Fuel Storage-Cask Testing Pad, Test Area North, Idaho National Engineering Laboratory. March 17, 1994.*

Options for the Long-Term Storage and Disposal of Spent Fuel

The Department completed in 1995 a comprehensive national environmental study to decide whether to leave the spent fuel at the sites where it is located or to consolidate it in a few regional locations or in one central place. The option selected was to store similar types of spent fuel together to optimize use of technical management expertise and in case some preparation of the spent fuel was required for long-term storage and disposal.

The Department is testing aboveground dry-cask storage designs for spent fuel that has cooled long enough in pools. Dry casks typically provide more reliable long-term storage than pools. Many commercial nuclear power plants already use this storage method. The Idaho Underground Dry Vault Storage Facility demonstrates a version of this method for the storage of spent fuel. One candidate for dry storage is the N Reactor spent fuel from the Hanford Site.

The current plan for the disposal of spent fuel– either as intact fuel elements or in some other form – is emplacement in a geologic repository mined deep in stable rock. There is widespread international agreement that this method of disposal can provide long-term isolation. Any spent fuel destined for geologic disposal will first have to be encapsulated in metal containers designed to meet regulations for performance in a repository. In some cases the spent fuel may require processing to prepare it for disposal or long-term storage. For example, damaged fuel may present too great a risk for storage. Also, spent fuel containing weapons grade, highly enriched uranium may require processing to avert potential security and criticality problems during storage or after disposal. The Department is considering new technologies for stabilizing spent fuel without reprocessing, which creates waste, contamination, radiation exposure and non-proliferation problems and is very costly.

A more detailed discussion of geologic disposal can be found on pages 45 and 46, although the repository described there is intended exclusively for transuranic waste.

The T Plant was the world's first reprocessing canyon. In 1944, it dissolved spent fuel from the Hanford B Reactor and chemically extracted the plutonium, which was then used to form the core of the Trinity and Nagasaki bombs. It continued reprocessing until 1956. Today, the plant is used to decontaminate equipment. *Hanford Site, Washington. July 11, 1994.*

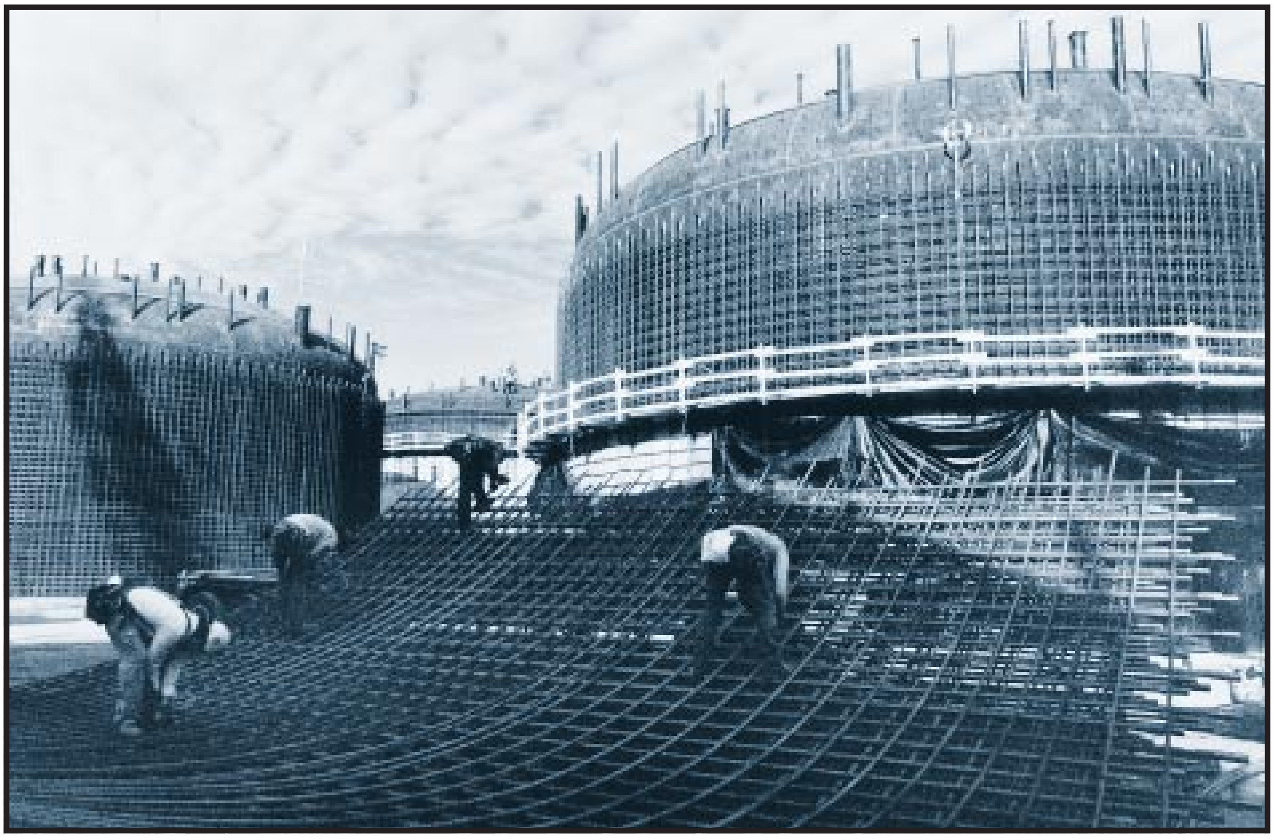
High-Level Waste from Reprocessing

Irradiated fuel and target elements discharged from a production reactor contain a variety of intensely radioactive fission products (the lighter isotopes resulting from the splitting of uranium) mixed with the desired plutonium and uranium. During the Cold War, these fuel elements were dissolved in acid and chemically processed to separate the plutonium and uranium. The acids and chemicals from these operations are known as "high-level waste." Nearly all of the fission products resulting from irradiation are contained in this liquid high-level waste.

High-level waste is the most radioactive byproduct from reprocessing and contains most of the radioactivity originally found in the spent fuel. The intense radioactivity is caused by the relatively rapid decay of many fission products. As a result, it will generate one-tenth as much heat and radiation after 100 years, and it will have decayed to 1 one-thousandth of its original level in 300 years. The decay helps make the handling of the waste safer and easier. Nonetheless, the waste will require disposal and isolation from the environment for a very long time, essentially as long as spent fuel.

The liquid high-level waste resulting from reprocessing is stored in 243 large underground tanks in four states.

For reprocessing operations, five facilities were built at Hanford, two at the Savannah River Plant, and one at the Idaho National Engineering Laboratory. These buildings and their underground tanks for high-level waste are among the most radioactive places in the United States. Four of the Hanford canyons and one at the Savannah River Site were primarily devoted to plutonium extraction. Two others (the second canyon at Savannah River and the one in Idaho) were used for extracting highly enriched uranium from spent fuel. The fifth Hanford canyon was briefly used to recover uranium from high-level-waste tanks. In addition, a demonstration plant for reprocessing commercial spent fuel was built and operated briefly in West Valley, New York. The high-level waste from this plant is also the Department's responsibility.



Million-gallon double-walled carbon-steel tanks under construction at Hanford. These tanks are designed to contain high-level radioactive waste from plutonium-production operations. They will replace older single-walled tanks, many of which have leaked. The new tanks are designed to last for 50 years. By that time it is believed that a long-term solution for high-level-waste disposal will have been developed. *Hanford Site, Washington. November 16, 1984.*

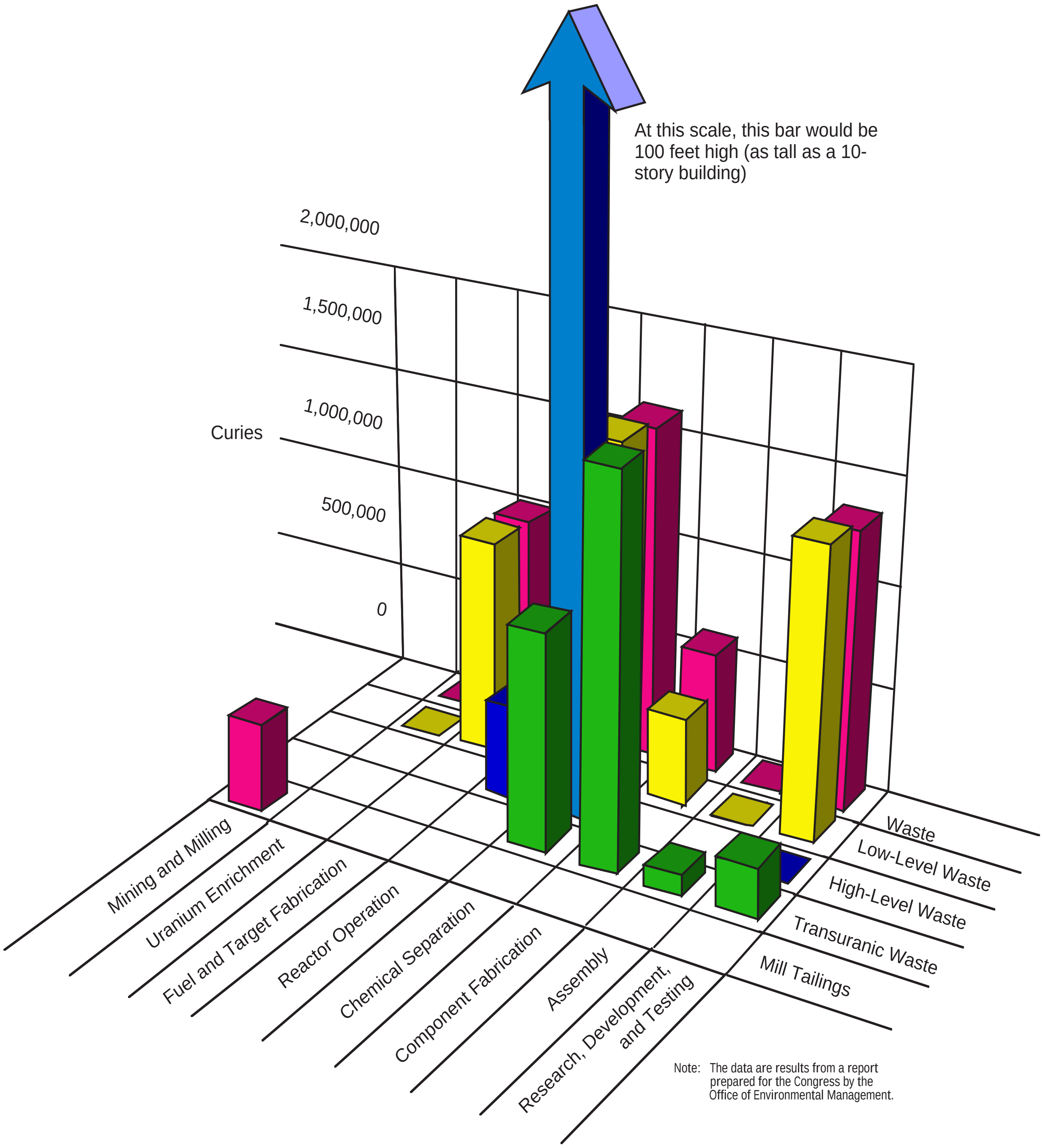
The Department currently stores about 100 million gallons of high-level waste–enough to fill about 10,000 tanker trucks–the largest volume of waste in the Department's inventory. Most of this waste has been stored in 243 underground tanks in Washington, South Carolina, Idaho, and New York. The waste stored in these tanks contains a variety of radioactive liquids, solids, and sludges. Some of the liquid has been converted to a concentrated dry form. Because workers during much of the Cold War often filled these tanks without first sampling the waste and without recordkeeping to today's standards, the Department does not have complete knowledge of some waste characteristics. If high-level waste is inadequately managed, it can pose serious immediate as well as long-term risks.

The older Hanford tanks were designed for a useful life of 25 years. By 1973, 15 of the tanks had experienced significant leaks into nearby soil and ground water. Currently 67 tanks at Hanford are known or suspected of having leaked high-level waste into the surrounding soil. The three largest leaks released 115,000, 70,000, and 55,000 gallons of high-level waste.

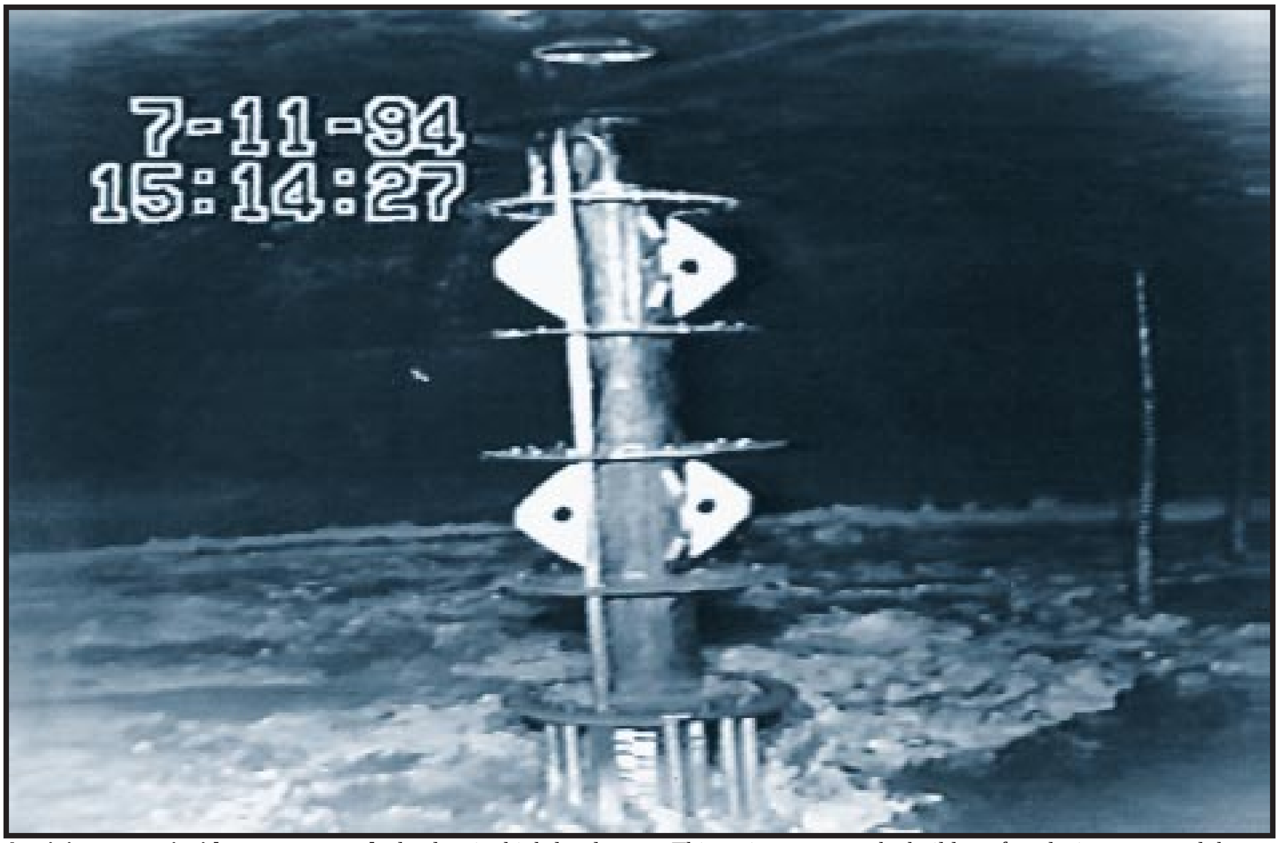
Reducing Risks from High-Level Waste

In some tanks, radioactive decay and chemical reactions generate hydrogen gas or other compounds that can explode under certain conditions. While the Soviets experienced an explosion of high-level waste with serious public health consequences in 1957, such an accident is not likely in the United States because both the chemical constituents of the waste and the storage conditions differ. It is, however, important to understand the circumstances of the event to ensure that it does not occur in the United States. The Department has made a major effort in recent years to reduce the possibility of a waste-tank explosion at Hanford.

Radioactivity in Wastes and Other Byproducts Generated by Nuclear Weapons Production Activities During the Cold War



Each step in the process of designing, producing, testing, and maintaining nuclear weapons produces wastes and other byproducts. Facilities across the United States have contributed to this process and generated a variety of wastes as a result. Knowing how much waste of what type has been generated by what steps in the process is critical for planning how to manage the wastes and possibly redesigning, for the future, the steps in the process to minimize the generation of these wastes and the attendant problems. This graph illustrates the amount of radioactivity contained in five types of waste and byproducts generated by nuclear weapons activities during the Cold War, with high-level waste from chemical separation accounting for 99 percent of the radioactivity. Another method for measuring the waste is by volume. (see page 25).



A mixing pump inside a storage tank slowly stirs high-level waste. This action prevents the buildup of explosive gases and thus minimizes the risk of an explosion. *Tank 241-SY-101, Hanford Site, Washington. July 11, 1994.*

Advanced robotics for cleanup of high-level waste are demonstrated by research scientist Jae Lew. The robotic manipulator in the distance is designed to break up and remove sludge and solidified waste inside a high-level-waste tank. This system is also used to develop, test, and evaluate a variety of methods for the retrieval of high-level waste. *337 Building, Hanford Site, Washington. July 11, 1994.*

A special mixing pump has been designed and installed at Hanford in the tank identified as having the highest risk of a hydrogen-gas explosion. Hydrogen had accumulated in the solids in the lower part of the tank, where it periodically "burped" up to the surface and into the tank's airspace. A spark could have caused an explosion, releasing high-level waste to the environment. The mixing pump circulates the waste in the tank, allowing hydrogen to escape at regular intervals and in safe concentrations through a filtered ventilation system, virtually eliminating the threat of explosion. A backup pump has been built and is ready to be installed if needed. Mixing pumps may also be installed in other tanks.

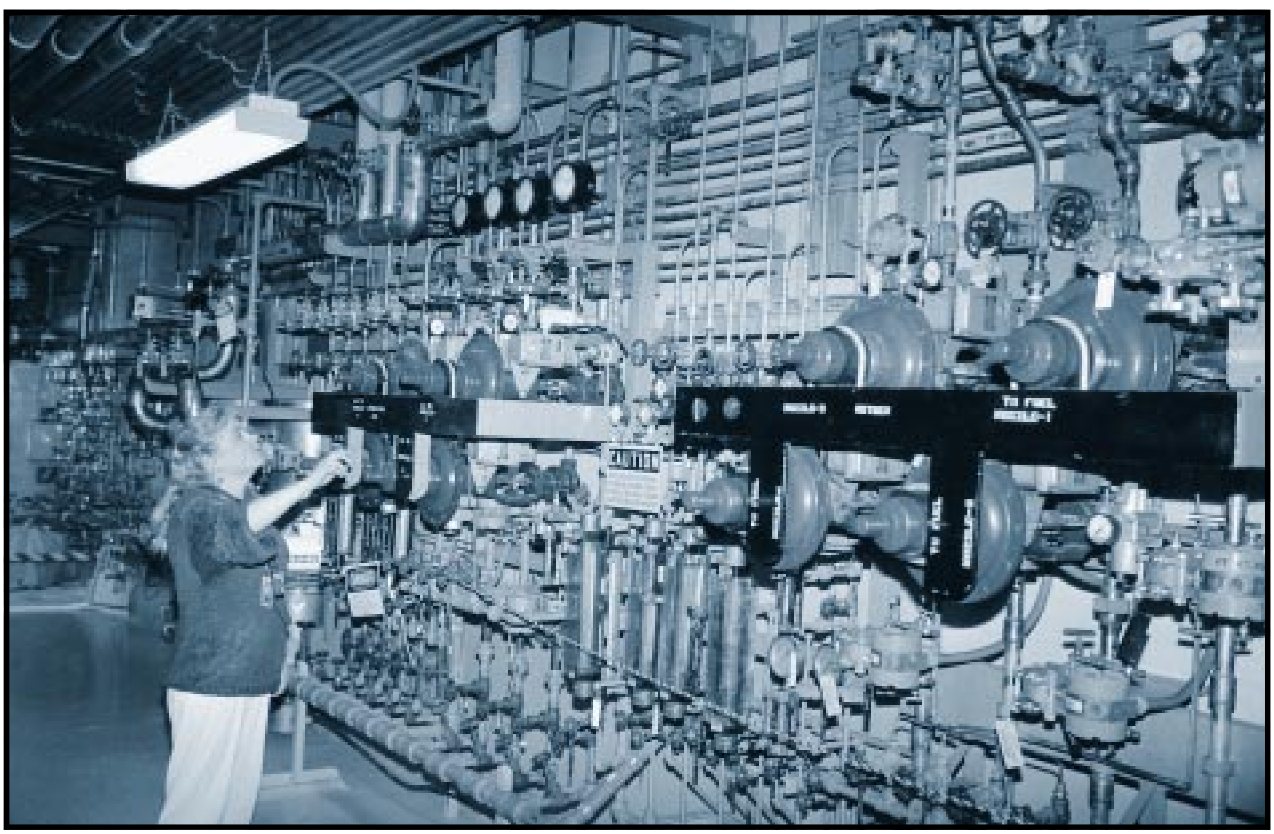
Another chronic problem at Hanford is that most of the original storage tanks for high-level waste were single-walled tanks made of carbon steel. The carbon steel corroded, and no provision had been made to contain material that leaked out of the tanks.

To help correct this problem, 28 new double-walled tanks of carbon steel and concrete were constructed in the 1980s with a life expectancy of about 50 years. Most of the free-standing liquids from the single-shell tanks has been transferred into the new tanks.

Some of the stored high-level waste is in a solid "saltcake" form. At present, this solid waste cannot be removed from its storage tanks without first dissolving it with water. The Department is designing advanced robotics equipment, controlled by operators from a safe distance, that will be capable breaking up and extracting this material.

Stabilizing High-Level Waste: Preparing for Disposal

Even after tens of thousands of years, high-level waste will remain radioactive. The Department of Energy is thus charged with ensuring that these materials are isolated from people and the environment for a very long time. In preparation for long-term disposal, the Department is developing ways to put the most radioactive byproducts of nuclear weapons production into more stable forms.



In a plant for calcining high-level waste, manager Judy Burton monitors the controls of the fluidized bed used to heat liquid high-level waste and convert it to powder. This reduces the volume of the waste by up to eight times. *Idaho National Engineering Laboratory. March 17, 1994.*

In Idaho, workers have converted much of the liquid high-level waste to a dry concentrated powder and stored it in bins, ready for final treatment in preparation for disposal.

This storage bin for calcined high-level waste is made of reinforced concrete and steel. Inside its 4-foot-thick walls are stainless-steel silos containing up to 55,000 cubic feet of high-level waste in powdered form. There are seven bins like this in Idaho, and they are engineered to provide safe storage for 500 years. *Idaho National Engineering Laboratory. March 17, 1994.*

Progress in Idaho

The Idaho National Engineering Laboratory has operated a calcining facility that uses heat to convert large quantities of liquid high-level waste into a dry powder for storage. The calcined waste occupies up to eight times less volume and is more stable than the liquid waste. The Department is upgrading the calcining plant and support facilities to meet current safety and environmental requirements.

After calcining, the powdered waste is stored in steel silos housed inside cylindrical concrete bins several feet thick. The vaults are engineered to contain the waste and to provide passive cooling. Direct human contact with the waste would be dangerous, and the dry waste could be dispersed easily. The Department is assessing which technology would be most suitable for converting the material into a more stable form for disposal in a permanent repository.

Despite this success in stabilizing waste, some high-level waste in Idaho remains in liquid form. Its high sodium content prevents calcining without significant dilution or treatment. Engineers are now developing methods to calcine the remaining liquids.

At other sites where reprocessing created this type of waste, workers are taking a different approach, which skips this intermediate step.

The Department is upgrading the calcining plant and support facilities to meet current safety and environmental requirements.

Converting Waste to Glass in South Carolina, New York, and Washington

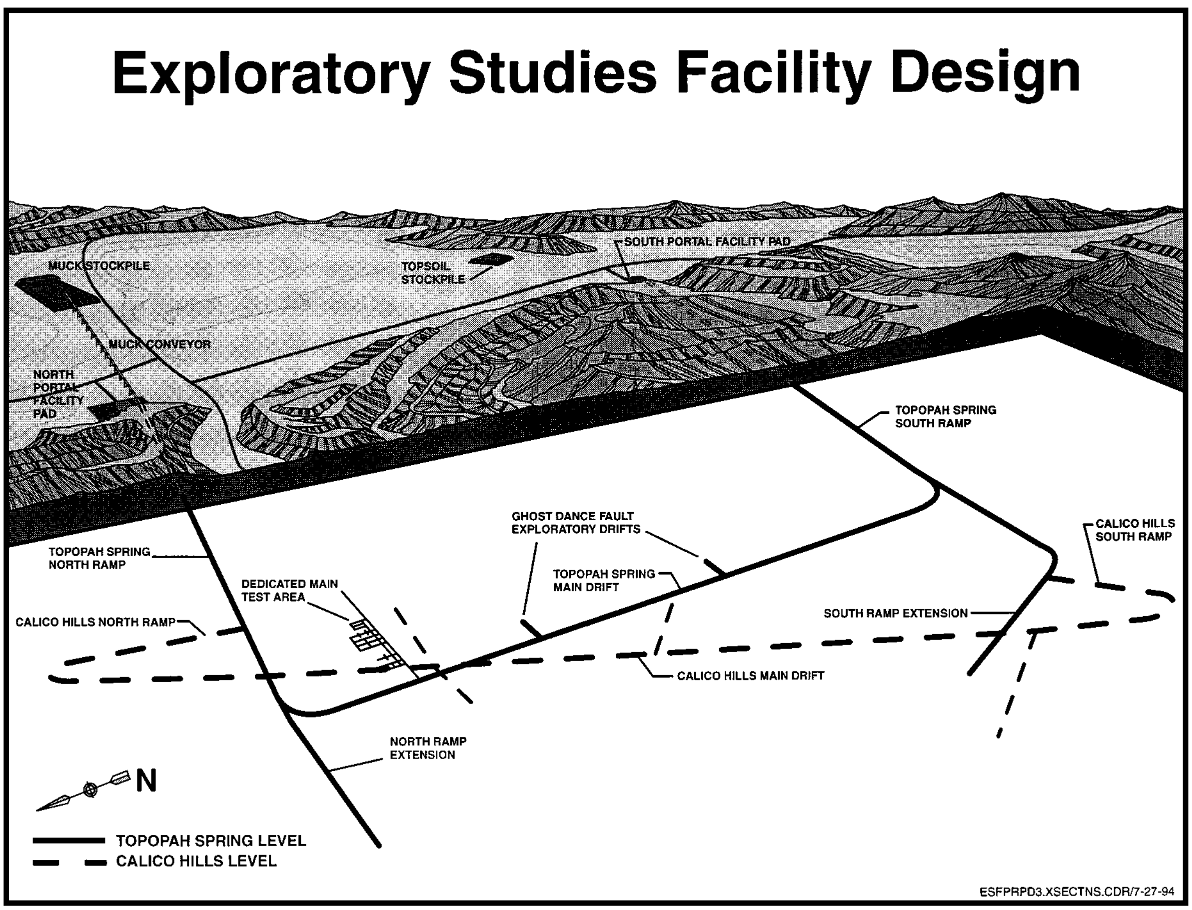
At the three other reprocessing sites, high-level liquid acidic wastes were neutralized for storage in carbon steel tanks. The resulting liquids, sludge, and saltcake will be mixed with molten glass, and poured into metal cylinders. Similar processes are already being used in Europe.

This method, called “vitrification,” poses a number of technical challenges. Any plant that processes high-level waste must be shielded and operated by remote control. In addition, some of the waste needs to be chemically treated to prepare it for vitrification. The process must be controlled carefully to avoid tank corrosion or the generation of dangerous gases. The waste to be treated has a variety of chemical forms that might prove difficult to blend with molten glass.

The Department has constructed two of the world’s most modern radioactive-waste vitrification facilities and has completed major testing prior to waste vitrification. At the South Carolina plant, workers produced more than 70 canisters of test glass in 1995. In addition, chemical treatment of wastes in preparation for vitrification was completed. The Savannah River Site in South Carolina plans 20 years of operation to vitrify existing high-level wastes. The other facility is a smaller plant at West Valley, New York, near Buffalo. The backlog of high-level waste at this plant will take several years to vitrify.

The Department of Energy is preparing to stabilize the most radioactive byproducts of nuclear weapons production for long-term storage and disposal.

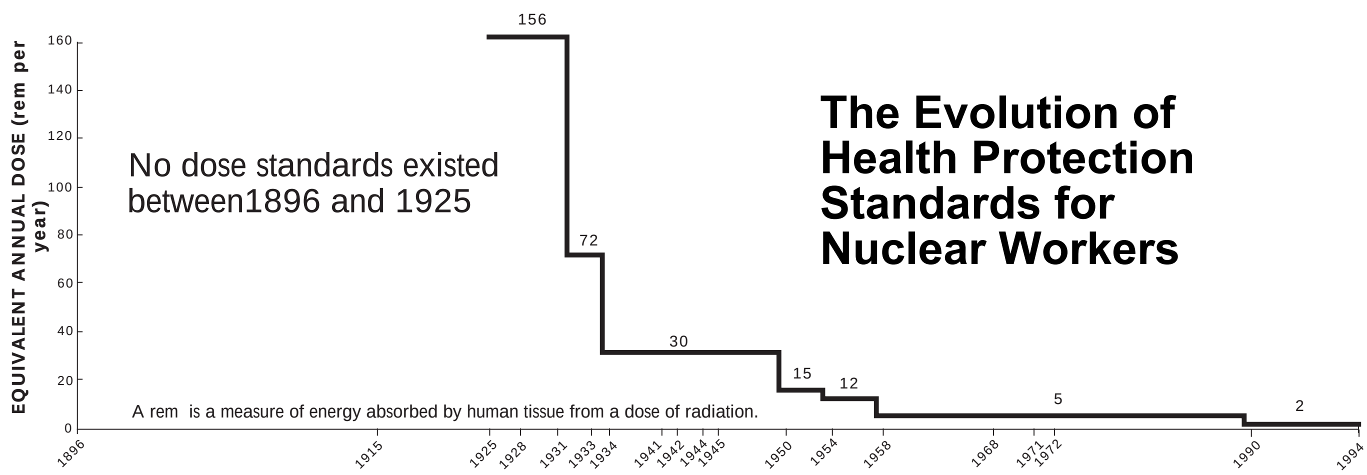
Vitrified waste will be poured into stainless-steel canisters that will be placed in a storage facility. In this form, the waste will cost much less to store and monitor than liquid waste. Once a geologic repository is ready, the canisters will be transported there for permanent disposal. If the Yucca Mountain, Nevada site that is currently the subject of characterization studies proves suitable, the Department expects to begin sending its high-level waste there by 2010.



A geologic repository at Yucca Mountain in Nevada would be laid out as shown in this drawing. The Yucca Mountain site has been studied for over 10 years to determine whether it is suitable for a repository. If the site is found to be suitable, the Department expects to start sending its waste to this geologic repository by the year 2010.

This vitrification plant for high-level waste is 120 yards long and encompasses 5 million cubic feet. It contains 69,000 cubic yards of concrete with 13,000 tons of reinforcing steel and 320,000 feet of electrical cable. It is designed to turn high-level waste into glass logs by pouring a mixture of waste and borosilicate glass into stainless-steel canisters, which are then sealed and stored. Workers completed major testing in 1995, including producing more than 70 canisters of test glass. *Defense Waste Processing Facility, Savannah River Site, South Carolina. January 7, 1994.*

These stainless-steel canisters weigh 1,100 pounds each. When full of vitrified waste, they will weigh 3,700 pounds each and will be extremely radioactive. *Defense Waste Processing Facility, Savannah River Site, South Carolina. June 15, 1993.*



There is no single set of radiation protection standards. This graph is based on recommendations, sometimes different, published by U.S. and international groups concerned with radiation protection. They have been translated into a single, consistent set of numbers and measurement units for the purpose of this summary.

1896 Henri Becquerel discovers radiation. First radiation injuries are reported, but no protection standards exist.

1915 Protection standards describing "safe practices" for handling radium and X-ray machines are published in Sweden and Germany. Radiologists are advised to stay as far away from their equipment as possible, to handle radium vials with tongs, and to work no more than 35 hours a week. The U.S. and Britain soon follow suit, but no dose limits are set because measurement techniques and units do not yet exist.

1925 Swedish and German scientists publish estimates of "tolerance doses," the amount of radiation a person is thought to absorb without harm. Based on the amount of radiation that would burn skin, the tolerance dose is initially estimated to be the equivalent of about 156 rem per year (over 45 times the current standard), although the estimates vary widely.

1928 The first internationally accepted X-ray protection standard, 1 one-hundredth of the amount that burns skin per month, is accepted at an international congress.

1931 The tolerance dose is standardized at 6 rem per month (72 rem per year).

1933 The genetic effects of radiation on fruit flies are studied by German scientist A. Mueller. He learned that radiation caused genetic mutations.

1934 First international radiation safety standards based on measurements of damage to human tissue are published in Zurich by the International Commission on X-Ray and Radium Protection. Workers are allowed up to 0.1 rem per day (30 rem per year).

1941 Recommended tolerance for ingested radium is initially set at 1 ten-millionth of a curie per person by the National Commission on Radiation Protection. This recommendation is based on studies of radium-watch-dial painters.

1942 The Manhattan Project begins. The 1934 radiation exposure standards of 30 rem per year are accepted by the University of Chicago's Metallurgical Laboratory after experimental verification. The "tolerance" concept is discarded in favor of the "maximum permissible exposure."

1944 The initial tolerance limit for plutonium inhalation is set at 5 millionths of a gram per person by the Manhattan Project's radiation protection laboratory.

1945 The first atomic bombs are produced, tested, and used. Weighting factors for the different types of radiation are introduced to account for their different health effects. The plutonium tolerance limit is lowered to 1 millionth of a gram per person.

1950 Scientists discard the idea of a "maximum permissible exposure," recognizing that any amount of radiation may be dangerous. Radiation protection scientists recommend that exposure be "as low as reasonably achievable." Concern over latent cancer, life shortening, and genetic damage also causes standards to be halved: 0.3 rem per week (15 rem per year).

1954 A quarterly limit of 3 rem per 13 weeks (12 rem per year) is introduced by the U.S. National Bureau of Standards to allow more flexibility in exposure patterns. Workers are still allowed 0.3 rem per week up to this limit.

1958 In response to a study by the National Academy of Sciences of the genetic effects of radiation, a new dose limit is introduced, using a formula that allows workers to receive 5 rem per year after the age of 18. Annual doses are allowed to exceed this level up to 3 rem per 13 weeks (12 rem per year). To protect the gene pool, a lower standard of 0.5 rem per year is set for the general public.

1968 The Federal Government updates its protection standard to the 5 rem per year recommended in 1958. This standard has not been changed since.

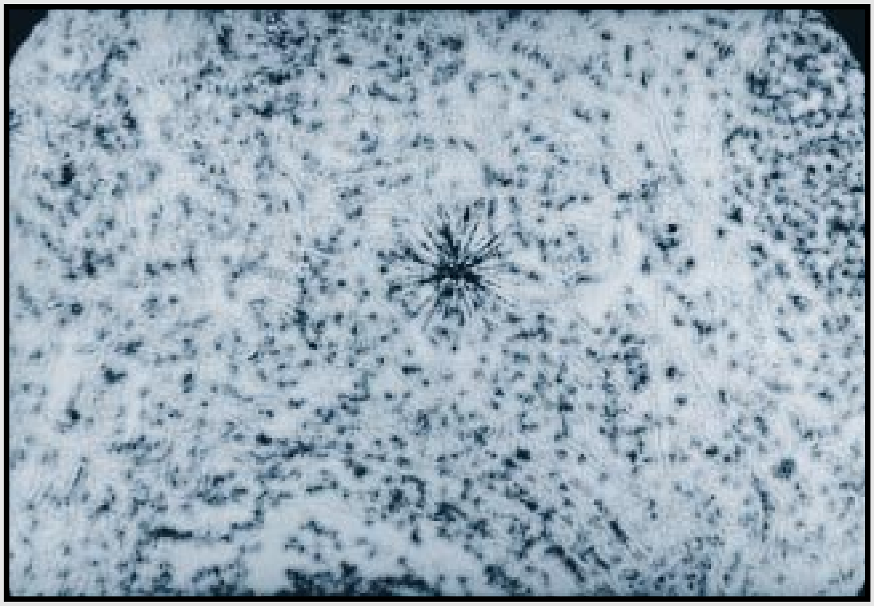
1971 Radiation protection standard is restated by the National Committee on Radiation Protection but not really changed: 3 rem per 13 weeks in the past, 5 rem per year in the future. By including exposure from internal radiation ("body burden"), the standard is effectively lowered by a significant amount.

1972 The National Academy of Sciences publishes its first study of the health effects of radiation since 1956. The report, Biological Effects of Ionizing Radiation I (BEIR I) becomes the first of a series.

1990 The National Academy of Sciences BEIR V report asserts that radiation is almost nine times as damaging as estimated in BEIR I. Annual doses may no longer exceed 5 rem per year. The International Commission on Radiation Protection recommends that an average dose of 1 or 2 rem per year not be exceeded.

Radiation and Human Health

Before 1896, scientists believed that atoms were immutable and eternal. The discovery of radiation changed this view forever. Since its discovery, scientists have studied radiation intensely. Its potential for commercial and medical benefits, and its health risks, became quickly apparent. In comparison with many nonradioactive chemicals, radiation is easy to detect and measure, and hundreds of studies have quantified its effects on living organisms. Nonetheless, it is not possible to predict its exact effects on a specific person. There is no doubt that high levels of radiation cause serious health damage. The precise effects of low-level radiation continue to be controversial.



Particle of plutonium in lung tissue. The black star in the middle of this picture shows tracks made by alpha rays emittted from a particle of plutonium in the lung tissue of an ape. Alpha rays do not travel far, but once inside the body they can penetrate the more than 10,000 cells within their range. *Magnification 500 times. Lawrence Radiation Laboratory, Berkeley, California. September 20, 1982.*

What Is Radiation?

Radiation is energy emitted in the form of particles or waves. Radioactive materials like radium are naturally unstable and spontaneously emit radiation as they "decay" to stable forms. Although the term "radiation"includes microwaves, radiowaves, and visible light, we are referring to the high energy form called "ionizing" radiation (i.e., strong enough to break apart molecules), which produces energy that can be useful, but can also damage living tissue.

Kinds of Radiation

There are four major types of radiation:

Alpha particles are heavy particles, consisting of two neutrons and two protons. Because the particles are slow moving as well as heavy, alpha radiation can be blocked by a sheet of paper. However, once an alpha emitter is in living tissue, it can cause substantial damage.

Beta particles consist of single electrons. They are moderately penetrating and can cause skin burns from external exposure, but can be blocked by a sheet of plywood.

Gamma rays are high-energy electromagnetic rays similar to X-rays. They are highly penetrating and several inches of lead or several feet of concrete are necessary to shield against gamma rays.

Neutrons are particles that can be both penetrating and very damaging to living tissue, depending on their energy and dose rate.

Measuring Radiation

One way to measure radiation is at its source. This is done by monitoring the rate at which the atoms in a radioactive element disintegrate. This mechanical measurement uses the "curie" as its basic unit, 1 curie being 37 billion atomic disintegrations in 1 second.

A different way is to calculate radiation energy at its point of impact in the body. This is the health-based approach. Its basic unit of measurement is the rem (roentgen-equivalent-man), and it is based on assumptions about the actual damage or accumulation of radioactivity in body parts, such as bones or lungs. These assumptions result in some uncertainty, but this approach allows more meaningful measurements than measuring energy levels from a source. Since a single radiation dose has different effects on different body organs, it is not easy to predict what effect a given dose will have on a person's health.

Half-Life

The less stable an atom, the more rapidly it breaks down and the shorter its half-life–the time required for half of the original atoms to decay. During a second half-life, half the remaining atoms, or one-quarter of the starting number, will decay, and so on. The half-lives of various isotopes range from fractions of a second to billions of years.

How Can Radiation Cause Damage?

In living organisms, the chemical changes induced by high doses of radiation can lead to serious illness or death. At lower doses, radiation can damage DNA, sometimes leading to cancer or genetic mutations. Even the natural background radiation level (which depends on geographic location, altitude, and other factors) imposes some risk of illness. An estimated 82 percent of the average radiation exposure received by people in the United States comes from natural sources.

Understanding Radiation Hazards

Measuring a substance's radioactivity is only the first step toward understanding its potential hazards to living organisms. Other important factors include:

Type of radioactivity. Some radiation, such as alpha particles, can cause chemical changes at short range. Other kinds, such as neutrons, can be harmful from distant external sources.

Chemical stability. Radioactive substances that can burn or otherwise react are more susceptible to being dispersed into the environment. For instance, some forms of plutonium can spontaneously ignite if exposed to air.

Biological uptake. Radioactive elements incorporated into organisms are more harmful than those that pass through quickly. Many radioactive elements are readily absorbed into bone or other tissues. Radioactive iodine is concentrated in the thyroid, while radium and strontium are deposited in bone. Insoluble particles like plutonium oxide can remain in lung tissue indefinitely.

Dose and dose rate. Dose rate is the amount of radiation received in a given time period, such as rem per day. In general, the risks of adverse health effects are higher when exposure is spread over a long period than when the same dose is received at one time.

Dose location. Some kinds of living tissue are more sensitive to radiation than others.

The combined effect of the above factors makes the risk posed by even a simple radiation exposure difficult to estimate. Real-world wastes from nuclear weapons production often contain many different radioactive constituents–along with various chemicals–introducing even more uncertainty. However, the hazards can be better defined by considering the particular types of radiation emitted by each radioactive element and by modeling likely pathways of exposure.

Plutonium metal puck. Plutonium must be handled and stored in small quantities like this to prevent it from spontaneously starting a nuclear chain reaction. *Rocky Flats, Colorado.*

The Plutonium Problem

Plutonium can be dangerous even in extremely small quantities, particularly if it is inhaled as a dust. Finely divided plutonium metal may ignite spontaneously if it is exposed to air above certain temperatures. Therefore, extraordinary precautions are required when handling it. The facilities that processed plutonium chemically and metallurgically or made the plutonium into high-precision warhead components are structurally similar to electronics industry “clean rooms” or research labs for the study of virulent diseases. Plutonium-production operations are enclosed in gloveboxes, which are filled with a dry inert gas or air at pressures lower than normal room air pressure. That way, if a leak develops, contamination will not flow outward.

The X-Y Retriever Room at the Rocky Flats Plant contains plutonium in many forms. During normal operations, plutonium in this room was recycled for warhead production. Today the room is used to store surplus plutonium. Here workers are making repairs to a hoisting mechanism. The hoist is used to lift the plutonium from the storage cans on the floor. *Building 707, Rocky Flats Plant, Colorado. November 29, 1988.*

Workers in these plants wear special anticontamination coveralls, rubber shoe covers, and two layers of surgical gloves – and, when necessary, respirators or "moon suits." Disposable coveralls, gloves, and shoe covers become radioactive waste after use on each work shift, every workday. Technicians carefully scan all employees with radiation detectors when they enter or leave certain areas to ensure that they have not been contaminated. The process is time-consuming but necessary to ensure safety.

To prevent diversion by terrorists, plutonium requires constant protection against theft. To further complicate matters, it must be handled carefully to avoid putting more than a few kilograms of it in close proximity. This must be done to prevent a burst of radiation known as a "criticality event." An inadvertent criticality event would not cause a nuclear explosion, but it would release intense radiation that can penetrate the shielding used in plutonium operations, and the radiation could be lethal to nearby workers.

Plutonium Residues and Scraps

There are many steps in the manufacture of plutonium parts for nuclear weapons. The sudden shutdowns of plants that did this work, including the Rocky Flats Plant in Colorado, the Hanford Site in Washington, and the Savannah River Site in South Carolina, stranded 26 tons of plutonium in various intermediate steps. The plutonium is in a wide variety of forms, from plutonium dissolved in acid to rough pieces of metal to nearly finished weapons parts. Scraps of metal and chemicals that contain enough plutonium to be worth recovering were stored in drums and cans. Unknown amounts of plutonium have collected on the surfaces of ventilation ducts, air filters, and gloveboxes.

The safe management of plutonium requires vigilance and caution under the best circumstances. The complexity of conditions in weapons plants presents an even greater challenge. Radioactivity from plutonium, some of it dissolved in corrosive acids, is slowly destroying the plastic bags and bottles that contain it. Flammable hydrogen gas is accumulating inside some of the sealed cans, drums, and bottles that clutter aisles and fill the gloveboxes. Bulging and ruptured containers have already been found in several places. Some of the plutonium is in a flammable form. In some cases, plutonium may be accumulating on the bottoms of tanks, where enough of it could result in a criticality event.

Some barrels of residues from plutonium operations are stored in drums in the building in which they were processed. *Building 776/777, Rocky Flats Plant, Colorado. December 20, 1993.*

Not only must plutonium be constantly inspected, guarded, and accounted for, but the buildings that house it also must be maintained. Ventilation systems and air filters must work continuously and fire and radiation alarms must be tested regularly. Men and women who work at the plants are at risk. Although they are less likely, severe accidents could endanger the nearby public and contaminate the environment.

These problems are among the Department's top priorities. All of the most urgent plutonium problems are now being addressed. Some of the ultimate solutions will take years to implement, but the work has begun. Workers at the Rocky Flats plant have been emptying bottles, draining tanks and pipes, and solidifying the liquids they remove. Pipes are already shrink-wrapped so they will not leak. New drains are being installed where needed, since almost half the liquids in the pipes and tanks cannot be removed otherwise. This work must be thoroughly planned and carefully executed. Most of the liquid plutonium at Rocky Flats will be solidified within 2 to 3 years.

In some cases, entire plants may have to be restarted to clean them out. For example, at the Savannah River Site's two chemical separation plants, more than 95,000 gallons of liquid containing dissolved plutonium have sat in tanks for several years. The Department began processing these hazardous solutions to stabilize them in 1995. Other unstable nuclear materials will be stabilized using a pilot-scale vitrification facility at the Savannah River Site.

Plutonium Metal in Storage

There are also problems with the plutonium-metal "pucks," "buttons," and other solid forms of plutonium metal kept in the storage vaults. This plutonium was stored in metal containers overpacked with plastic bags, and the bags were then sealed. In some cases, however, there are no exact records of what is contained in the sealed packages. Furthermore, the plutonium "rusts" into a powder when exposed to air. This powder can burn, and it could be inhaled by workers who must handle it. To eliminate these problems, the containers are being opened so that the plutonium dust can be brushed off and "roasted" in a special oven, thereby converting it to a more stable form for storage. The metal and powder are then repackaged separately without plastic to prevent the problem from recurring.

Brushing plutonium to remove oxidized portions is conducted inside gloveboxes. Scott Sterkel, a worker at Rocky Flats, carries out brushing on a plutonium button. The powder that is brushed off will be roasted to convert it to a more stable form. *Rocky Flats, Colorado. July 11, 1994.*

This high-security fence at Hanford's Plutonium-Uranium Extraction (PUREX) Plant was designed to safeguard strategic nuclear materials. Currently, this guardhouse, once staffed with guards, is used as an entry point for employees. PUREX operations ceased in 1990. *Hanford Site, Washington State. July 11, 1994.*

Informed Debate About Disposition

The United States produced and extracted more than 100 metric tons of plutonium for nuclear weapons during the Cold War; if the plutonium is not in operational warheads, it is currently stored at facilities across the country. The Department began thinking about switching from plutonium production to long-term storage and disposition even before the fall of the Soviet Union and the declassification of United States stockpile data. In February 1988, then Secretary of Energy John Herrington told a Congressional subcommittee that we were "awash in plutonium." In 1989, a National Academy of Sciences panel, using classified data, concluded that additional plutonium production was unnecessary. Now, however, the plutonium surplus continues to increase as each day more plutonium is removed from dismantled weapons at the Pantex Plant in the Texas panhandle and stored in World War II-era bunkers, at a rate of about 2,000 warheads per year.

The fate of all U.S. surplus plutonium must be determined publicly. Meaningful decisions about plutonium disposition can only be made through informed public debate, which has only recently begun with the release of vital information. For example, until Secretary of Energy Hazel R. O'Leary declassified plutonium stockpile information in December 1993, the public did not know how much plutonium the United States had produced (approximately 100 metric tons).

Scientists, engineers, policymakers, arms-control specialists, economists, and others are debating the fate of surplus plutonium in the United States. One fundamental question is whether the Department's plutonium is an asset or a liability. The United States spent billions of dollars to produce the plutonium it now possesses. Some argue we should recover this investment by fueling nuclear power plants with plutonium. Proposals have been made to fuel a new tritium-production reactor with it. Others contend this would be uneconomical, and we should find the safest, fastest, cheapest way to make it unusable for nuclear weaponry. One proposal is to vitrify it, just as is planned for high-level waste. Disposal suggestions have included deep geologic repositories, deep boreholes, and disposal in the ocean beneath the seabed. This issue is under intense study within the executive and legislative branches.

Drums of transuranic waste in interim storage in Idaho inside a tension-support structure. The waste in these drums will be disposed of at the Waste Isolation Pilot Plant (WIPP) if the repository meets all regulatory requirements. *WIPP Certification Station, Stored Waste Examination Pilot Plant, Idaho National Engineering Laboratory. March 17, 1994.*

The fate of surplus plutonium will be determined by addressing issues related to international security as well as environmental protection. Whatever decision is made in the United States will affect similar decisions being considered in other countries. One result could be smaller stockpiles of nuclear weapons material throughout the world. For example, using plutonium in a reactor or blending it with high-level waste could render it as inaccessible as if it were in spent nuclear fuel, which was the standard suggested by the National Academy of Sciences in a recent study.

While final decisions are being made, new technologies are needed to stabilize plutonium quickly without creating more radioactive waste than necessary. The Department has already developed two new technologies for this purpose at Hanford.

Another fundamental question revolves around the definition of plutonium wastes. Any material for which the cost of recovering the plutonium it contained was less than the cost of producing new plutonium was not previously considered waste. This definition is no longer appropriate after the end of plutonium production era.

Transuranic Waste

Nearly everything involved in plutonium processing becomes contaminated and must be contained and monitored indefinitely. Generally, such waste is called “transuranic” waste. Technically, this includes any material containing significant quantities of plutonium, americium, or other elements whose atomic weights exceed those of uranium. Transuranic waste can include everything from chemicals used in plutonium metallurgy to used air filters, gloves, clothing, tools, piping, and contaminated soils.

Accidents as well as normal operations have generated transuranic waste. The Rocky Flats Plant experienced numerous small fires in its production lines, and two major fires, in 1957 and 1969. Firefighting and subsequent decontamination efforts generated thousands of drums of waste, much of which was shipped to the Idaho National Engineering Laboratory for storage. Portions of the buildings are being decontaminated, and machinery and other wastes are being compacted and packaged for storage. Other problems, such as accidental releases of plutonium solutions, have rendered entire rooms in some buildings unusable.

Throughout the nuclear weapons complex, the transuranic waste inventory in storage totals about 100,000 cubic meters, or the rough equivalent of half a million 55-gallon drums. As in the case of spent fuel and high-level waste, much of the transuranic material was placed in temporary storage under the assumption that a permanent repository would soon become available. In the meantime, some containers have corroded, requiring costly cleanup, repackaging, and relocation.

Progress in Managing Transuranic Waste

In recent years, the Department of Energy has made a major effort at consolidating, repackaging, monitoring, and sheltering its transuranic waste. Transuranic waste has not always been stored with adequate safety. For example, thousands of drums have been exposed to the elements, risking corrosion and leaks. These are now being stored on concrete or asphalt pads under weather-resistant structures. Furthermore, much of the transuranic waste remains in earth-covered berms, which were expected to be needed for only a few years until a permanent disposal site became available. New storage facilities for this waste are being built, and drums that are corroding or leaking will be overpacked in clean metal containers. These interim steps will ensure safe storage until disposal in a geologic repository can begin.

Permanent Disposal

The long-lived radioactivity of plutonium, combined with the hazards if it is released even in small quantities, requires that transuranic waste be permanently isolated.

The Department of Energy has decided that deep underground disposal in a geologic repository is the best solution in terms of safety, cost, and practicality. This decision is based on recommendations by the National Academy of Sciences, many years of geologic investigations and experiments, and environmental studies. Waste in the proper forms and configurations, if emplaced in stable geologic formations, should be isolated with a high degree of confidence for tens of thousands of years.

Scientists in many countries agree that a geologic repository must be located in a rock formation with certain specific properties. For example, there must be evidence that the formation has been stable for millions of years; the rock

Demonstration models of special casks for shipping transuranic waste show how transuranic wastes will be trucked cross-country to the Waste Isolation Pilot Plant. Each of these TRUPACT-II (Transuranic Package Transporter) casks can hold fourteen 55-gallon drums. A window in the center cask displays mock waste drums cut open to reveal typical constituents of transuranic waste. This “roadshow” flatbed unit is used for public education and for training emergency-response teams along planned waste-shipment routes. *Waste Isolation Pilot Plant, near Carlsbad, New Mexico. February 25, 1994.*

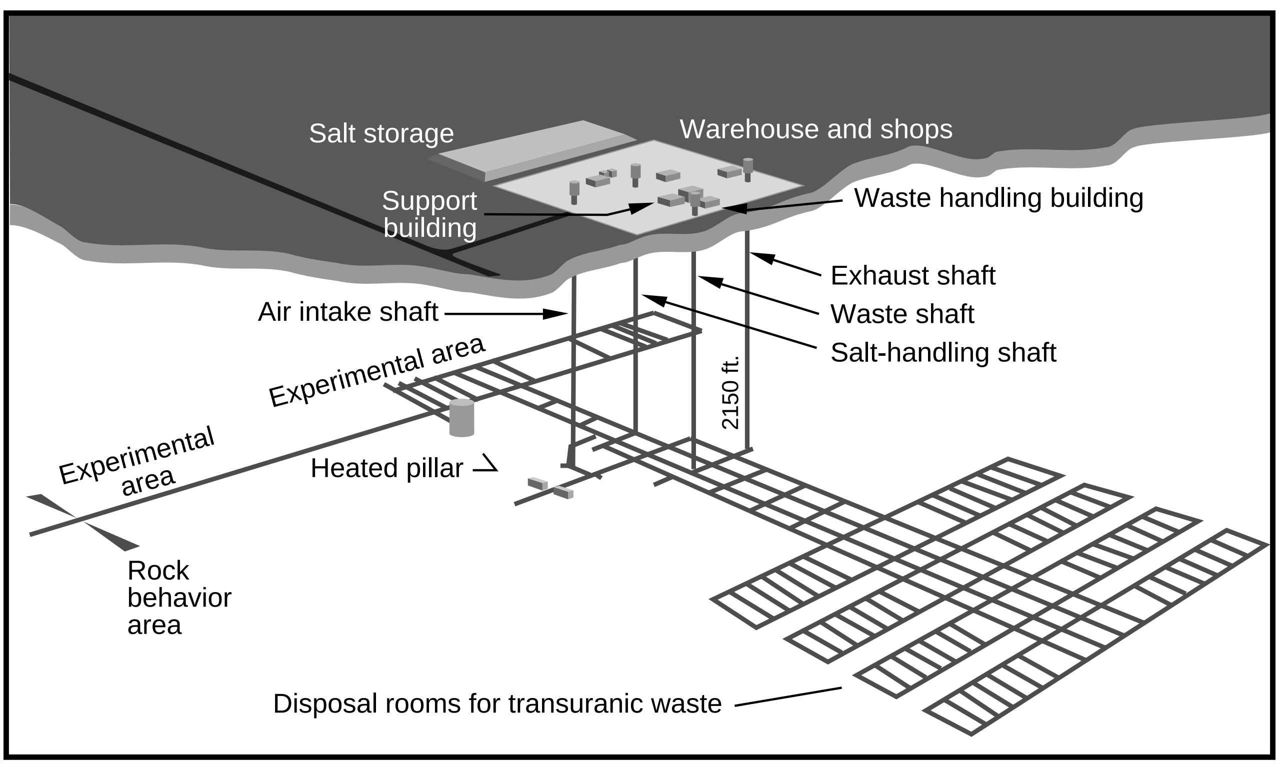
must be free of circulating ground water; and the site should be located in an area with little potential for frequent and severe earthquakes or volcanic eruptions. In addition, the rock formation should be sufficiently deep beneath the surface and thick enough to allow the excavation of a repository with sufficient buffers of the same rock both above and below it. Also desirable is the absence of valuable natural resources which might attract inadvertent human intrusion into the repository in the distant future.

In the mid-1970s, the Department identified a site in southeastern New Mexico, near Carlsbad, as a promising candidate. The chosen rock formation was a thick layer of rock salt that had been deposited some 200 million years ago. The repository was to be excavated 2,150 feet below the surface. After environmental studies were completed in 1979, the Congress authorized the Department to build the repository, called the Waste Isolation Pilot Plant (WIPP). Large rooms have been excavated in the salt, and they are connected to the surface by several shafts to provide ventilation and to move excavated rock and waste containers. Surface facilities to receive the waste, inspect it, and move it underground have been built and equipped.

To create the WIPP, the Department excavated tunnels 2,150 feet deep in a thick layer of rock salt deposited 200 million years ago.

Many experiments have been completed or are underway at the WIPP site to provide a better understanding of how the salt in the repository will behave and how waste materials will interact with the underground environment. No wastes have been taken to the site yet.

A vital part of the process for determining the suitability of the WIPP for disposal is providing opportunities for public involvement. Citizens groups, Native American Tribes, State and Federal agencies, and an independent technical review panel have been involved in a process to determine whether the WIPP can provide the required isolation for at least 10,000 years. The final decision will be made by the Environmental Protection Agency, which will assess the expected performance of the WIPP to determine whether it will meet environmental standards for the disposal of transuranic waste. If the decision is favorable, shipments of waste could begin in 1998.



A simplified layout of the Waste Isolation Pilot Plant, showing the surface facilities, the four shafts, the underground areas in which experiments are conducted, and the underground rooms in which transuranic waste will be disposed of if disposal is approved.

Emergency exhaust airway at the WIPP. Should an accidental release of radiation occur within the WIPP's system of underground chambers, exhaust ventilation air would be diverted through a bank of filters to clean the air before it is released through this duct. *Waste Isolation Pilot Plant, Carlsbad, New Mexico. February 25, 1994.*

This underground waste-disposal room, excavated in 1986, was the first of 56 chambers to be excavated at the WIPP. It is 300 feet long, 33 feet wide, and 13 feet tall and could hold six thousand 55-gallon drums of transuranic waste. It lies 2,150 feet below the surface of the earth. *Room 1 of Panel 1, Waste Isolation Pilot Plant, near Carlsbad, New Mexico. February 25, 1994.*

In parallel with the scientific and regulatory processes, the Department of Energy is working to characterize the waste that would qualify for disposal at the WIPP. If the WIPP is approved for permanent disposal, most of the transuranic waste now in storage would eventually be emplaced there. However, there is also a large amount of transuranic material that in its current form contains too much plutonium to be acceptable at the WIPP.

Low-Level Radioactive Waste

As defined by law, "low-level waste" is a catch-all term for radioactive waste that is not high-level waste, transuranic waste, spent fuel, or mill tailings. The Department's policy also allows certain other materials to be managed as low-level waste: small volumes of material used for nuclear research and development, material contaminated with small concentrations (less than 1 ten-millionth of a curie per gram of waste) of transuranics, and small concentrations of naturally occurring radioactive material as well as waste produced in research projects. Virtually any activity involving radioactive materials generates some low-level waste. This waste can include a wide variety of forms and radioactivity levels. The physical forms of low-level waste include rags, protective clothing, contaminated equipment, waste resulting from decontamination and decommissioning, construction debris, filters, and scrap metal.

Low-level waste is also generated by commercial power reactors and facilities producing fuel for them. In addition, it also comes from industrial sources and research laboratories. Another source is the world of medicine, where radioactive isotopes are used for diagnosis and treatment.

Most of the Department's low-level waste has been packaged in drums or boxes and buried in shallow pits and trenches. Approximately 3 million cubic meters has been disposed of in this way.

"Low-level waste" is a catchall term for radioactive waste that is not high-level waste, transuranic waste, spent fuel, or mill tailings.

This engineered trench for low-level waste contains approximately 30,000 stacked carbon-steel boxes of waste, each box being 4 by 4 by 6 feet. It stopped receiving waste in 1995. In 1996, the site will be backfilled with dirt to form a mound, which will be seeded with grasses and sloped for runoff. Once this trench is closed, the trench-burial of low-level waste here will stop. *Engineered Low Level Trench 4, Solid Waste Management Burial Grounds, Savannah River Site, South Carolina. January 7, 1994.*

Newly Generated Low-Level Waste

Although weapons production has been suspended, some low-level waste is still being generated. In fact, low-level waste accounts for more than 80 percent of the Department's newly generated waste, which consists of clothing, tools, and equipment used in cleanup operations, contaminated soils, dismantled buildings and machinery.

To improve efficiency, the Department is stressing waste minimization and early characterization and segregation of waste to reduce the generation of low-level waste requiring disposal. In addition, treatment methods are being improved to reduce waste volumes and provide more stable waste forms. Minimizing waste volume reduces the cost of disposal and extends the life of disposal facilities. More stable waste forms enhance the overall safety of disposal.

Some low-level liquid waste is a byproduct of efforts to consolidate and stabilize high-level waste for permanent disposal. This liquid waste is being stored temporarily, and some of it is being made into a material called "saltstone" (the waste, which contains various metallic salts, is mixed with concrete). This material is being disposed of in vaults designed to isolate it from the environment.

Managing Low-Level Waste

Low-level waste is currently disposed of at the Nevada Test Site, Hanford, the Savannah River Site, Oak Ridge, Los Alamos, and the Idaho National Engineering Laboratory. Unique wastes, including hull sections of decommissioned nuclear submarines, have been shipped to Hanford and the Nevada Test Site for disposal.

In all cases, newer buried low-level waste is required to meet much more stringent disposal standards. In some cases, many former disposal sites are being re-evaluated to decide whether there is economic or environmental justification for digging up and treating the wastes and contaminated soil. For instance, at a trench in Idaho that contained about 38 kilograms of plutonium, the low-level waste was excavated, packaged, and stored for later disposal.

This new vault for storing low-level waste contains 12 large cells, each of them 55 feet long, 150 feet wide, and 30 feet high. The first facility of its kind in the country, this vault system will replace shallow burial in engineered trenches at the Savannah River Site. This vault began storing waste in September 1994. Once full, it will be covered with clay to form a mound with a plant cover. *E Area Vault, Solid Waste Management Division, Savannah River Site, South Carolina. January 7, 1994.*

At the Rocky Flats Plant, about 700,000 gallons of contaminated sludge from five solar evaporation ponds was first consolidated into a single pond and is now being transferred to about 70 large double-walled polyethylene tanks. This program will isolate the material and alleviate concerns that ground and surface waters will be further contaminated while a cost-effective long-term treatment is selected.

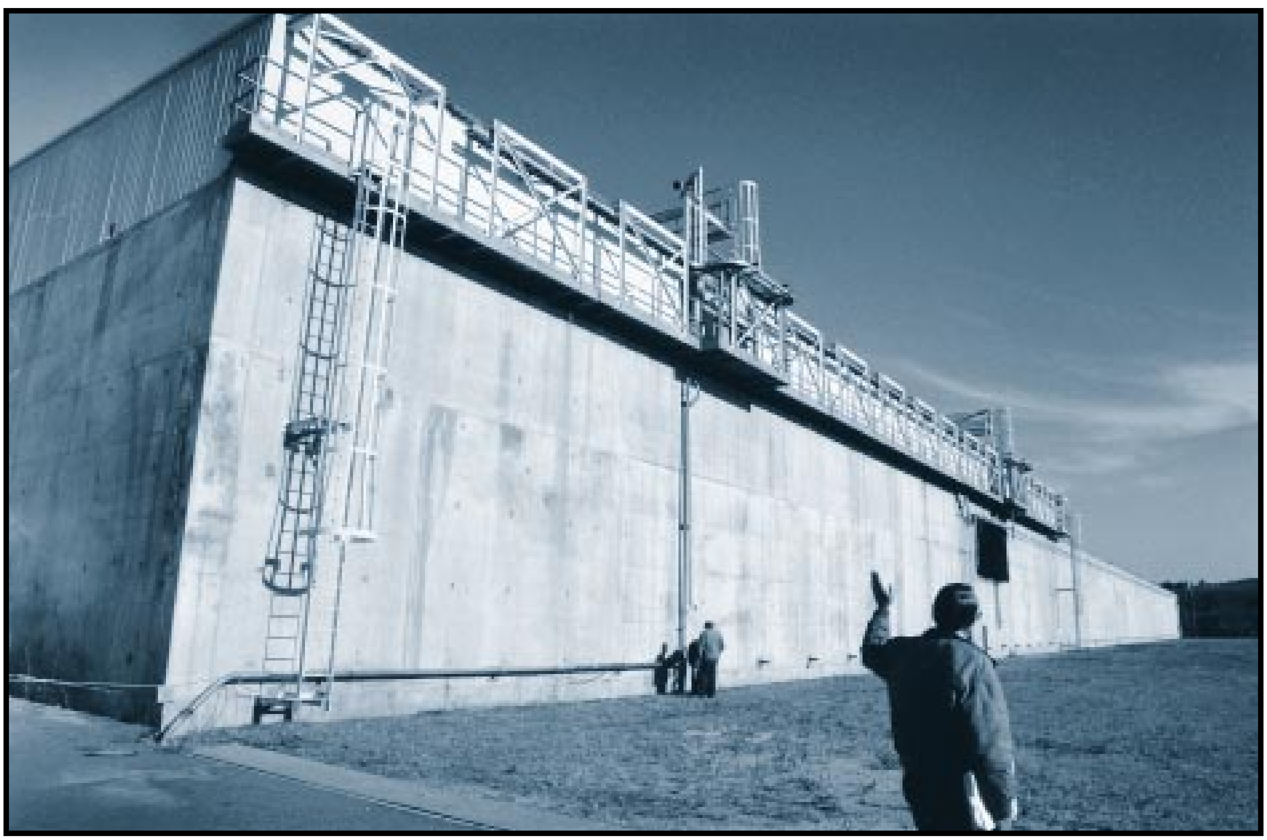
Researchers at Rocky Flats are exploring methods of mixing radioactive waste with recycled polyethylene so that it can be poured into drums or other forms for disposal. Large quantities of polyethylene beverage containers are already discarded in landfills, where the longevity of the plastic slows organic decomposition. A combination of low-level waste and waste plastic would take advantage of polyethylene's durability, while reducing waste-plastic in conventional trash landfills.

At Fernald, a vitrification technology is being developed for treating wastes contaminated with uranium and other natural radioactive isotopes. Using a process similar to high-level-waste vitrification, the Department will make wastes into glass pebbles, or "gems," that are much more resistant to leaching than the original waste.

Since the 1980s, the Department has safely operated some below grade containment wells and above grade disposal facilities for low-level solid waste at Oak Ridge. The construction of two new facilities will begin in 1995 and 1998.

The Savannah River Site has constructed and begun operating some low-level-waste vaults to replace the traditional shallow-land-burial trenches.

Some types of low-level waste, such as high-activity waste, require greater confinement than that provided by shallow land burial. To determine a disposal method for these wastes, the Hanford Site and the Nevada Test Site are evaluating the design and use of engineered facilities.



The Z-Area vault for low-level-waste in saltstone form is a 25-foot-tall reinforced-concrete structure 600 feet long and 200 feet wide, housing 12 concrete cells that will be filled with solid grout. The grout is made of a low-level radioactive solution mixed with cement, fly ash, and slag. The chief radionuclides locked into the grout are technetium 99, strontium 90, and cesium 137. Once all 12 cells are filled, the vault will be covered with earth and capped with clay. *Savannah River Site, South Carolina.*

Hull sections of decommissioned nuclear-powered submarines are put in disposal trenches. The used nuclear fuel is removed from the sections of submarine hulls that contain nuclear reactors. The radioactively contaminated hull sections with the defueled reactors inside are then transported by barge to Hanford, where they are placed in a trench for burial. *Trench 94, Hanford Site, Washington. July 12, 1994.*

Use of the thick submarine hull as a disposal container provides extra isolation between the environment and the low-level waste and toxic lead that remain after the reactor fuel is removed. *Trench 94, Hanford Site, Washington. December 20, 1993.*

A burn cage is used at the Pantex site to dispose of items associated with the shipping and handling of high explosives used to make nuclear warheads. Wooden and cardboard crates and other materials contaminated with high explosives are burned inside the cage. *Burning ground, Pantex Plant, Texas. November 18, 1993.*

Hazardous Waste

Although radioactive waste certainly presents hazards, a waste is not legally considered "hazardous" unless it contains other chemicals or exhibits particular characteristics, such as being ignitable or corrosive under some circumstances. This legal distinction is important because if a waste is determined to be "hazardous" under the solid- and hazardous-waste law known as the Resource Conservation and Recovery Act, a rigorous set of regulations applies. Some States, such as Washington, have established additional requirements for other wastes considered "dangerous." A landmark legal case in 1984 determined that hazardous-waste requirements do apply to waste that contains radioactivity as well as hazardous constituents–so-called "mixed waste." The Energy Department has successfully negotiated agreements with appropriate states to treat these wastes and is committed to complying with these requirements.

The Department's hazardous (non-radioactive) wastes are essentially the same as industrial chemical wastes produced by private corporations and, in much smaller quantities, by most households. They include organic solvents remaining from an incomplete chemical reaction, sludges from degreasing operations, heavy metals from unrecycled batteries. Generally, the Department uses private vendors to remove hazardous waste from its sites and to treat it and dispose of it in compliance with regulations.

Although hazardous waste may present more conventional and familiar risks than the radioactive wastes generated by the Department, it is important to note that safe handling requires substantial expertise and training, and constant vigilance. In the past, like many private companies, the Department has often failed to take adequate precautions in handling, storing, treating, or disposing of hazardous waste. The result is significant environmental contamination that now requires expensive remediation. In some cases, stored waste is discovered for which no records are available to characterize it. These "unknowns" can be among the riskiest wastes to manage.

Like private industry, the Energy Department has learned that the best way to manage hazardous waste is to minimize the amount generated or to eliminate its generation in the first place.

Mixed Hazardous and Radioactive Waste

All high-level waste and most transuranic waste is mixed waste, usually because of the presence of organic solvents or heavy metals in addition to radioactive components. In this discussion, however, the term “mixed waste” is used to mean *low-level* radioactive mixed waste.

The hazardous component of mixed waste is regulated under the Resource Conservation and Recovery Act. In 1992, President Bush amended this act by signing into law the Federal Facility Compliance Act (FFCA), which, among other provisions, expanded the regulation of the Department of Energy’s mixed waste. The FFCA made Federal facilities subject to the same fines and penalties as any private corporation if they violate the law. The law also requires the Department to develop plans for mixed-waste treatment, subject to approval of the states or the Environmental Protection Agency.

While the Department increased its compliance with environmental requirements for purely chemically hazardous wastes during the 1970s and 1980s, it accumulated large amounts of mixed waste in storage because of a lack of treatment and disposal facilities. As of 1984, however, the Resource Conservation and Recovery Act required that much of this waste be stabilized in preparation for disposal and not indefinitely stored. The Department is now faced with an enormous challenge–where and how to treat the large backlog of waste.

It may take many years to develop suitable treatment technologies, build facilities, and treat the existing backlog of mixed waste.

A Fernald worker overpacks rusting 55-gallon drums of low-level mixed waste by sealing them inside larger new 85-gallon drums. Some 50,000 deteriorating drums of Fernald waste stored outdoors for many years are being overpacked in a project that began in the late 1980s. *Plant 5, formerly the Metals Production Plant, Fernald Environmental Management Project, Fernald, Ohio. December 28, 1993.*

This incinerator in Oak Ridge burns radioactive and mixed hazardous radioactive wastes. Licensed for operation by the Environmental Protection Agency, it is the only one of its kind in the United States. *Toxic Substances Control Act Incinerator, Oak Ridge, Tennessee. January 10, 1994.*

To develop treatment plans, the Department, in conjunction with the National Governors' Association, has been working closely with the 22 states in which its mixed wastes are stored. New or improved cost-effective technologies also are being pursued. In general, radioactivity was not considered when technologies for commercial hazardous wastes were being developed; however, some can be adapted to deal with it. The Department has used an incinerator at Oak Ridge, Tennessee, to treat some mixed waste, but its technologies are not large or versatile enough for all treatment needs. Alternative, innovative technologies like plasma furnaces, vitrification, and polyethelyene encapsulation, promise to improve performance, reduce risks, and increase economic efficiency beyond the existing technologies of incineration and cementation. However, it may take many years to develop suitable treatment technologies, build facilities, and treat the existing backlog of mixed waste. During that time the Department will work with regulators, Native American Tribes, and the public to develop adequate disposal facilities.

The encapsulation of low-level mixed waste in polyethylene is an innovative waste-handling technology in a pilot phase at Rocky Flats. A heated stream of recycled polyethylene is combined with simulated low-level mixed radioactive waste, encapsulating each particle of waste as the mix is poured into molds. *Building 881, Rocky Flats Plant, Colorado. March 21, 1994.*

The vitrification of low-level mixed waste was demonstrated during the Minimum Additive Waste Stabilization pilot project. This demonstration used nonradioactive waste simulating soils and sludges contaminated with uranium and thorium. It produced several thousand kilograms of thumbnail-sized glass pebbles. This innovative technology makes wastes more stable while reducing waste volume and rendering them safer for disposal. *MAWS Facility, Fernald Environmental Management Project, Fernald, Ohio. December 28, 1993.*

Other Materials in Inventory

With the end of the Cold War, many valuable materials once used as primary materials or recycled back into the production cycle are no longer needed for their original purposes. Such materials range from plutonium residues in gloveboxes to large cylinders of depleted uranium gas to huge piles of contaminated and uncontaminated scrap metals. Some of these materials can be recycled or reused; others may no longer have an economically feasible use. In any case, the Department is working to ensure these materials are managed safely and in an environmentally sound manner.

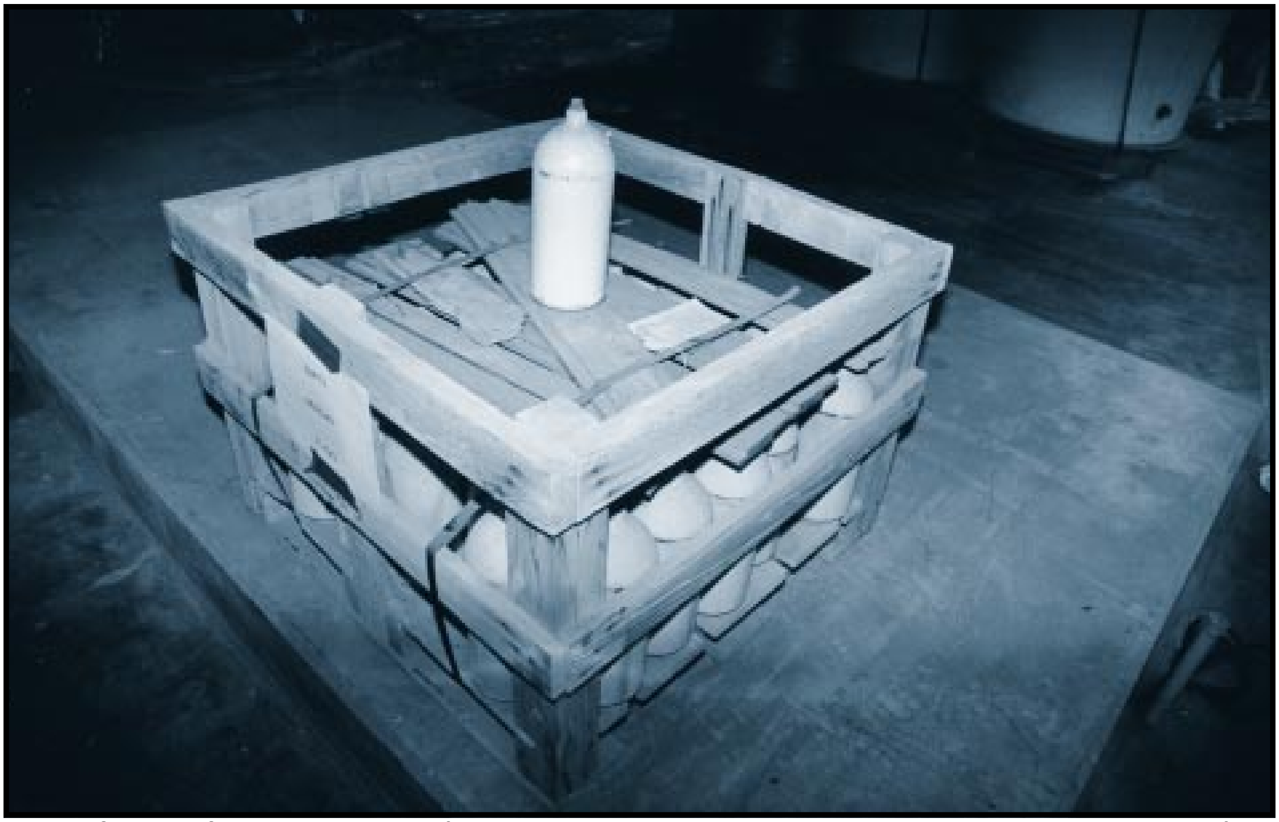
The Department owns thousands of 10- and 14-ton-capacity steel cylinders filled with depleted uranium hexafluoride from uranium enrichment. During the Cold War, some of this depleted uranium was used to make nuclear weapons parts, targets for plutonium reactors, "tank killer" bullets, and armor-plating used in the 1991 Gulf War. The Department is now working with state regulators and other interested parties to determine the best options for managing its remaining inventory of depleted uranium hexafluoride.

Many thousands of tons of scrap steel, copper, nickel, and other metals are located at sites throughout the nuclear weapons complex. Some of this scrap metal is radioactively contaminated. The Department's policy is to assume that scrap metal is contaminated unless proven otherwise. The Department is investigating ways to recycle some of these materials.

The Department also owns a variety of hazardous chemicals throughout the complex–from small vials containing toluene at the Los Alamos and Livermore Laboratories to large tanks of radioactively contaminated nitric acid at the Hanford and the Savannah River Sites. Many chemicals and chemical residues were left in containers or in process lines when the production of nuclear weapons came to a halt. The strategy for managing these chemicals emphasizes (1) the removal of excess or unneeded chemicals, (2) proper storage, and (3) improved inventory tracking and control.

The inventory includes a variety of other materials like lead, concrete shielding, lithium, and sodium. The Department must ensure that all of these materials are managed safely; it intends to work with regulators and other citizens to determine long-term options for these materials.

This yard for contaminated scrap metal contains heaps of slightly radioactive scrap steel, ferrous metal, and nickel-plated metal left over from upgrades and renovations to the K-25 Gaseous Diffusion Plant at Oak Ridge over the years. *K-25 Scrapyard, Oak Ridge, Tennessee. January 10, 1994.*



A crate of mercury flasks, which were used for lithium-enrichment operations at the Y-12 plant. Lithium must be enriched before it can be used as a target inside a reactor to produce tritium for nuclear weapons. Lithium enrichment was shut down in 1962, leaving about 35,000 areas where mercury remained in the operational equipment; some of it has migrated into the environment. *Y-12 Plant, Oak Ridge, Tennessee. January 11, 1994.*

These Mark 31 depleted uranium target element inner cores are part of the Department's large inventory of nuclear materials left "in the pipeline" when the Cold War ended. These materials are no longer needed for their originally intended use. The Department will work with regulators and other interested parties to determine how materials like these should be managed. *Plant 6, formerly the Metals Fabrication Plant, Fernald Environmental Management Project, Fernald, Ohio. December 28, 1993.*

Aerial view of the F Area at the Savannah River Site. This is one of the two chemical separation areas at the site. It covers just over half a square mile. All facilities shown on the facing page are within 5 miles of this spot. Visible in this photograph are the F Area Seepage Basin before closure (lower right), the F Area Tank Farm (group of circles near the bottom center), the 242-F Evaporator (between the two rows of tank tops), and the 221-F Canyon (long building above parking lot). *F Area, Savannah River Site, South Carolina. August 6, 1983.*

Waste-Handling Complications

It was necessary to construct a vast network of industrial facilities to mass produce materials and parts for nuclear weapons. Similarly, another chain of plants and processes is needed to contain, stabilize, treat, store, and prepare for disposal the resulting radioactive wastes. Each process leads to others, and each generates waste that must be handled. The cleanup of contamination also generates wastes that must be managed carefully, and each step in this process typically generates more waste.

There are thousands of industrial buildings and structures throughout the Department's sites. To the uninitiated observer, there is no apparent relationship among them. Yet each is inextricably linked to the others. An understanding of these connections is critical to the success of the environmental management mission. An example of how these connections interact, how one process or facility leads to another, is perhaps best illustrated by the chain of processes at the Savannah River Site, seen on page 59.

An understanding of the connections between facilities is critical to the success of the Environmental Management mission.

Savannah River Site Connections

1. To produce plutonium for nuclear warheads, we placed uranium “targets” in nuclear reactors and bombarded them with neutrons.

2. To extract plutonium from reactor targets, we built reprocessing “canyons,” which generated liquid high-level radioactive waste.

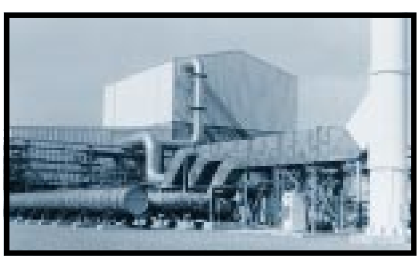
3. To store the liquid high-level radioactive waste from the reprocessing canyons, we built underground storage tanks.

4. To handle the low-level waste from reprocessing, we built burial grounds.

5. To make space for more liquid high-level radioactive waste in the storage tanks, we built evaporators to reduce the waste volume.

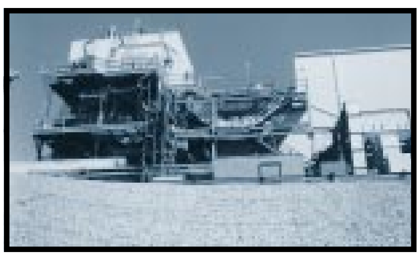
6. To dispose of wastewater that the evaporators removed from the high-level waste tanks, we built seepage basins.

7. To arrest spreading ground-water contamination from waste poured into the seepage basins, we built clay caps over them and installed pumping wells.



8. To provide an alternative for discharging effluent from the evaporators, we built the Effluent Treatment Facility.

9. To stabilize the liquid high-level radioactive waste in the storage tanks, we built the Defense Waste Processing Facility.



10. To reduce the volume of liquid high-level waste, we built the In-Tank Precipitation Facility.

11. To solidify the volume of liquid waste not processed by the Defense Waste Processing Facility, we built the Saltstone Facility.

12. To store the waste from the Saltstone Facility, we built the grout vaults.